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The effectiveness of PjBL-STEM learning models in improving High school students' deep learning skills in Artificial Intelligence topics

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Abstract

This study investigates the role of Project-Based Learning integrated with Science, Technology, Engineering, and Mathematics (PjBL-STEM) models in enhancing high school students' deep learning skills within the domain of Artificial Intelligence (AI). As AI becomes increasingly ingrained in our society, fostering a deep understanding among students is critical. Traditional teaching methods often emphasize rote memorization, which may not sufficiently develop higher-order thinking skills. Conversely, PjBL-STEM promotes active learning, problem-solving, creativity, and collaboration, which are key attributes of deep learning. This paper explores theoretical foundations, reviews relevant literature, discusses implementation strategies, and analyzes empirical evidence, ultimately demonstrating that PjBL-STEM significantly enhances deep learning in AI topics at the high school level.

Keywords: PjBL, STEM, Deep learning, Artificial Intelligence.

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1. Introduction

Artificial Intelligence (AI) is transforming virtually every sector, from healthcare to finance, and is becoming a fundamental competency in modern education. The rise of AI necessitates a shift in pedagogical strategies to prepare students not only to understand AI concepts but also to engage critically and innovatively with AI-related challenges.

High school education plays a crucial role in laying the groundwork for AI literacy. However, traditional didactic teaching often falls short in developing deep comprehension and critical thinking. This has led educators and researchers to advocate for more interactive, student-centered curricula such as Project-Based Learning (PjBL). When combined with

STEM education, this approach referred to as PjBL-STEM, encourages students to engage in meaningful, real-world problems.

Given this context, this paper assesses the effectiveness of PjBL-STEM in fostering deep learning skills related to AI among high school students and discusses how this pedagogical model can be optimized.

2. Literature Review

2.1. Introduction to AI in Education

Artificial Intelligence (AI) has transitioned from being a specialized field of computer science into an integral part of modern society, influencing various sectors such as healthcare, finance, transportation, and communication. As AI's capabilities and applications expand, it becomes essential that education systems globally equip students with foundational AI literacy [1]. AI literacy involves understanding core concepts such as machine learning, data analysis, algorithms, and ethical considerations while fostering critical thinking and problem-solving skills [2].

Numerous studies emphasize the need to integrate AI education across K-12 curricula to prepare students not only to understand AI technology but also to participate actively in societal debates about its responsibilities and challenges [3]. Incorporating AI topics in high school curricula is seen as vital to develop future scientists, technologists, and informed citizens capable of navigating a technologically driven world.

2.2. The Challenge of Teaching AI at the High School Level

Teaching AI effectively at the high school level poses unique challenges:

- Technical Complexity: Concepts like neural networks, deep learning, and algorithms require a level of abstract thinking that can be demanding for young learners [4].
- Resource Constraints: Schools often lack access to sufficient hardware, software, and trained teachers capable of delivering AI content [5].
- Curriculum Gaps: Many educational systems lack standardized curricula for AI, leading to inconsistent coverage and depth [6].
- Student Engagement: Traditional didactic teaching often fails to inspire interest or foster deep understanding among students regarding AI's implications and functionalities [7].

These challenges highlight the need for pedagogies that are engaging, accessible, and aligned with 21st-century skills development.

2.3. The Concept of Deep Learning in STEM Education

Deep learning, in an educational context, refers to a student's ability to understand concepts profoundly, transfer knowledge across contexts, analyze complex problems, and create novel solutions [8]. It contrasts with surface learning, which often emphasizes memorization and rote recall.

2.4. Bloom's Taxonomy and Higher-Order Skills

Bloom [9] classifies cognitive skills from lower to higher levels, with deep learning aligning with analysis, evaluation, and creation. Developing these skills is crucial in mastering AI topics, which require understanding underlying principles, evaluating ethical impacts, and designing innovative AI applications [10].

2.5. The Significance of Deep Learning in AI Education

Deep learning enables students to go beyond learning facts to critically interrogate AI's applications and implications [11]. For example, understanding biased data in machine learning models or ethical concerns about AI decision-making involves analytical and evaluative skills. Promoting deep learning helps develop computational thinking, creative problem-solving, and ethical reasoning [12]. Deep learning has emerged as a critical pedagogical approach in STEM (Science, Technology, Engineering, and Mathematics) education, emphasizing understanding, critical thinking, and the ability to apply knowledge in real-world contexts. Unlike surface learning, which focuses on rote memorization and superficial engagement, deep learning promotes meaningful learning processes that foster higher-order thinking skills. Deep learning originates from cognitive psychology and educational theory, particularly constructivist models that advocate active learning and knowledge construction [13, 14]. It encourages students to connect new information with prior knowledge, analyze concepts critically, and develop a comprehensive understanding. In STEM education, this approach aligns well with the goal of nurturing innovative and problem-solving skills essential for the 21st century [15]. Several studies highlight that deep learning in STEM involves inquiry-based activities, project-based learning, and the integration of real-world problems [16]. These strategies actively engage students in exploration, experimentation, and reflection, which facilitates a deeper grasp of complex concepts. For example, Freeman et al. [17] found that active learning approaches significantly improve student performance and retention in STEM disciplines compared to traditional lecture-based methods. While the benefits of deep learning are widely recognized, implementing it in STEM curricula faces challenges such as curriculum rigidity, assessment limitations, and varying student motivation. Educators need to redesign instructional strategies and assessment tools to truly support deep learning [18]. Technology-enhanced learning environments, including simulations and collaborative platforms, have been shown to support deep engagement [19]. Research suggests that fostering deep learning can lead to improved critical thinking, creativity, and problem-solving abilities among students, skills crucial for STEM careers [16]. Therefore, educators and policymakers are encouraged to create supportive learning environments that prioritize inquiry, reflection, and active participation, promoting deeper understanding and long-term retention of STEM concepts.

2.6. Pedagogical Strategies for Promoting Deep Learning

Educational research underscores the limitations of traditional lecture-based instruction, especially for complex, multidisciplinary subjects like AI. Alternative pedagogies that promote active engagement, collaboration, and authentic problem-solving are gaining prominence. Deep learning is an educational goal that emphasizes understanding, critical thinking, and the ability to transfer knowledge to real-world situations. To cultivate deep learning, educators must employ effective pedagogical strategies that actively engage students in meaningful exploration of content. Various approaches have been identified in the literature as effective in promoting deeper comprehension and long-lasting learning outcomes. Inquiry-based learning (IBL) encourages students to ask questions, investigate problems, and develop solutions through active engagement. According to the National Research Council [20], IBL fosters critical thinking and conceptual understanding by positioning students as creators of knowledge rather than passive recipients. This strategy promotes curiosity and a deeper grasp of the subject matter. PBL is a student-centered approach where learners tackle complex, real-world problems, thereby promoting deep understanding and application of knowledge [21]. Studies have shown that PBL enhances higher-order thinking skills and contextualizes learning, making it more meaningful and memorable [22]. Collaborative learning involves peer discussion, teamwork, and shared reflection, which significantly contribute to deep learning [23]. Collaborative activities facilitate exposure to diverse perspectives, critical discourse, and collective problem-solving, all of which reinforce understanding. Reflection involves students evaluating their own learning processes and conceptual understanding [24]. Incorporating reflective activities such as journaling or think-pair-share encourages deeper cognitive processing and self-awareness, crucial elements of deep learning. Modern pedagogical practices integrate technology such as simulations, virtual labs, and collaborative platforms to promote active participation and deeper engagement [19]. Technology facilitates experiential learning and allows for personalized exploration, which supports deep conceptual understanding. Constructivist strategies, grounded in the theories of Piaget and Vygotsky, emphasize active learner involvement in constructing knowledge through hands-on activities and social interaction [25, 26]. These approaches foster a deeper engagement with content, moving beyond memorization to meaningful learning.

2.7. Active Learning and Constructivism

Active learning approaches involve students actively constructing knowledge through hands-on activities, discussions, and reflective practices [27]. Constructivist theories [26, 28] support the notion that learners build new understanding based on prior knowledge, making engagement with real-world problems essential. Rooted in the work of Piaget [29] and Vygotsky [26], constructivism posits that learners actively construct their own understanding and knowledge of the world through experiences and social interactions. Piaget's cognitive development theory emphasizes that learners interpret new information through existing mental schemas, thereby actively building meaning. Vygotsky highlighted the importance of social context and collaboration, suggesting that cognitive development is profoundly shaped by the Zone of Proximal Development (ZPD), which learners navigate with the guidance of more knowledgeable others. Active learning involves pedagogical strategies that engage students directly in the learning process, prompting them to analyze, synthesize, and evaluate information rather than passively receive it Bonwell and Eison [30]. Techniques such as discussions, problem-solving, case studies, and peer teaching foster active participation. Evidence suggests that active learning leads to improved understanding, greater retention, and enhanced problem-solving abilities [17]. Many studies affirm that active learning is rooted in constructivist principles. By engaging students in meaningful activities, active learning facilitates knowledge construction aligned with constructivist views. Prince [27] emphasized that active learning promotes higher-order thinking skills, metacognition, and deeper understanding, which are central to constructivist pedagogy. Moreover, problem-based learning (PBL) and inquiry-based approaches exemplify the implementation of constructivist ideas within active learning frameworks. Research consistently demonstrates the positive impact of integrating active learning and constructivist strategies in diverse educational contexts. For instance, Freeman et al. [17] found that active engagement significantly increases student performance and reduces failure rates in STEM disciplines. Similarly, Bonwell and Eison [30] highlighted that student-centered activities increase motivation and foster the critical thinking core goals of constructivism.

2.8. Inquiry-Based Learning

Inquiry-based learning emphasizes questioning, investigation, and discovery. It aligns well with AI education, where students explore algorithms, data sets, and ethical challenges through guided inquiry [31].

2.9. Problem-Based Learning (PBL)

PBL is a student-centered pedagogy where learners solve open-ended problems, promoting deep understanding and transferable skills [32]. PBL fosters critical thinking, teamwork, and self-directed learning traits essential in mastering AI.

2.10. Project-Based Learning (PjBL)

While similar to PBL, PjBL emphasizes extended projects that often culminate in presentations, products, or solutions [33]. PjBL contextualizes learning, making abstract AI concepts tangible and relevant, thus fostering deeper engagement [34].

2.11. Integrating STEM Education with PjBL

STEM education aims to integrate science, technology, engineering, and mathematics into cohesive learning experiences. It prepares students for future careers in the sciences and addresses real-world problems holistically [35].

2.12. Rationale for STEM in AI Education

AI inherently involves multidisciplinary knowledge mathematics (statistics, linear algebra), programming (technology), engineering principles, and scientific inquiry. Integrating STEM in AI teaching ensures students grasp the interconnectedness of these domains, producing more meaningful learning [36].

2.13. PjBL as a Means of Achieving STEM Goals

Research indicates that PjBL enhances STEM learning outcomes by encouraging collaboration, inquiry, and application of knowledge [37]. Students engaged in STEM-based PjBL projects demonstrate improved understanding and retention, higher motivation, and increased confidence in science and technology [38].

2.14. Effectiveness of PjBL-STEM in Promoting Deep Learning

Empirical evidence supports the claim that PjBL-STEM enhances deep learning skills among high school students.

2.15. Enhanced Engagement and Motivation

Studies reveal that project-based approaches foster higher levels of motivation and interest, especially when projects are authentic and relate to real-world issues [39]. Engaged students are more likely to invest effort, reflect deeply, and develop complex understanding.

2.16. Development of Critical Thinking and Problem-Solving Skills

Research shows that PjBL promotes higher-order thinking, such as analysis and synthesis, critical for AI mastery [40]. Students learn to evaluate data critically, troubleshoot issues, and innovate solutions.

2.17. Promoting Collaboration and Communication

AI projects often require teamwork. PjBL fosters communication skills, negotiation, and collective reasoning [41]. These social skills underpin deep learning, as students articulate and defend their ideas.

2.18. Acquisition of 21st-Century Skills

Skills such as digital literacy, adaptability, and lifelong learning are cultivated through PjBL initiatives [42]. These skills are intrinsic to mastering AI content and navigating the evolving digital landscape.

2.20. Long-term Retention and Transferability

Research suggests that project-based activities promote better retention of concepts and transfer of skills to novel contexts [43]. Students are more capable of applying AI concepts learned through PjBL to real-world problems.

2.21. Challenges and Considerations in Implementing PjBL-STEM for AI

Despite promising evidence, implementing PjBL-STEM for AI education faces several challenges:

- Resource Limitations: Hardware, software, and training resources are often inadequate, especially in under-resourced schools [6].
- Teacher Preparedness: Effective PjBL requires teachers skilled in facilitating inquiry and managing multidisciplinary projects [44].
- Curriculum Constraints: Rigid curricula may restrict the flexibility needed for project-based activities focused on AI [45].
- Assessment Difficulties: Measuring deep learning and project outcomes necessitates sophisticated formative and summative assessments [46].

Addressing these challenges involves policy support, professional development, curriculum redesign, and technological investments.

2.22. Future Directions for Research and Practice

Further research is vital to understanding long-term impacts, optimal project designs, and scalable models for integrating PjBL-STEM into AI education.

Potential future trends include:

- Use of AI-powered tools to personalize PjBL experiences and assessments [47].
- Cross-disciplinary collaborations between schools, industries, and universities to develop authentic projects.
- Development of open educational resources (OER) to democratize access to AI PjBL curricula.
- Teacher training programs focusing on PjBL, AI pedagogy, and technology integration.

3. Methodology

3.1. Research Design

This study conducted a mixed-methods research approach, combining quantitative assessments of student learning with qualitative interviews and observations.

3.2. Participants

Participants included 120 high school students from four schools in urban and rural settings, divided into control (traditional instruction) and experimental (PjBL-STEM) groups.

3.3. Procedures

The experimental group engaged in AI-focused PjBL-STEM activities over a semester, which involved designing AI algorithms, applying machine learning techniques, and participating in ethical debates. The control group followed a conventional curriculum.

3.4. Data Collection Instruments

- Pre- and post-tests measuring AI knowledge and deep learning skills.
- Student reflective journals.
- Teacher interviews.
- Classroom observations.

3.5. Data Analysis

Quantitative data subjected to t-tests and ANOVA; qualitative data analyzed via thematic coding.

4. Results (with Data Analysis Tables)

4.1. Quantitative Findings: Data Analysis

To visualize the effects of the PjBL-STEM model, we analyzed students' scores from pre- and post-tests focusing on **deep learning skills in AI**. The following table summarizes the mean scores and standard deviations for both groups.

Table 1.
Presented compares the results of a pre-test and post-test assessment between two groups.

Group	Pre-Test Mean Score	Post-Test Mean Score	Mean Difference	p-value	Effect Size (Cohen's d)
Control (Traditional)	65.2 ± 8.4	68.1 ± 7.9	2.9	0.092	0.36 (small)
Experimental (PjBL-STEM)	64.8 ± 8.5	78.3 ± 6.5	13.5	<0.001**	0.85 (large)

Note: The p-value less than 0.05 indicates statistically significant improvement.

Group: The classification of participants into either control (traditional learning) or experimental (PjBL-STEM approach). Pre-Test Mean Score: The average score of participants before the intervention. Post-Test Mean Score: The average score after the intervention. Mean Difference: The difference between post-test and pre-test scores. p-value: Statistical significance of the difference, with values less than 0.05 indicating significant improvement. Effect Size (Cohen's d): Measures the magnitude of the intervention's effect, with 0.2 indicating a small effect, 0.5 a medium effect, and 0.8 a large effect.

4.2. Results (Expanded)

The summarized data clearly demonstrate that students involved in the PjBL-STEM learning model significantly outperformed their peers in traditional instruction, with a mean post-test score increase of approximately 10 points, compared to only 3 points in the control group. The effect size indicates a large impact of the intervention on deep learning skills.

5. Discussion

5.1. Impact of PjBL-STEM on Deep Learning

The data corroborate previous research that PjBL-STEM promotes deeper conceptual understanding. Specifically, engaging students in authentic AI projects encourages them to go beyond memorization, analyze complex data, and develop innovative solutions.

5.2. Challenges and Considerations

Implementation challenges include teacher training, resource availability, and curriculum alignment. Addressing these is vital for successful adoption.

5.3. Implications for Practice

Integrating PjBL-STEM into AI education requires curriculum redesign, professional development, and support systems. Emphasizing reflection and iterative testing enhances deep learning.

6. Conclusion

The integration of PjBL with STEM education significantly enhances high school students' deep learning skills in AI. This pedagogical approach aligns well with the skills required in the rapidly evolving digital economy, fostering not only knowledge but also critical thinking, creativity, and ethical awareness essential for AI literacy.

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